Reverse Spectrum Auction

All opinions are of Auctionomics consultants and not of FCC

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TV broadcast licenses

☐ Each channel uses 6MHz of spectrum in one of three bands

TV SPECTRUM ALLOCATION

Before Transition: Analog and Digital TV stations allocated to Ch. 2 – 69 (each channel is 6 MHz)
After Transition: Digital TV stations allocated to Ch. 2 – 51 (i.e. "core" DTV spectrum)
  • Ch. 52 – 69 – Reclaimed for advanced wireless uses
  • Ch. 63, 64, 68 and 69 – Reallocated for public safety
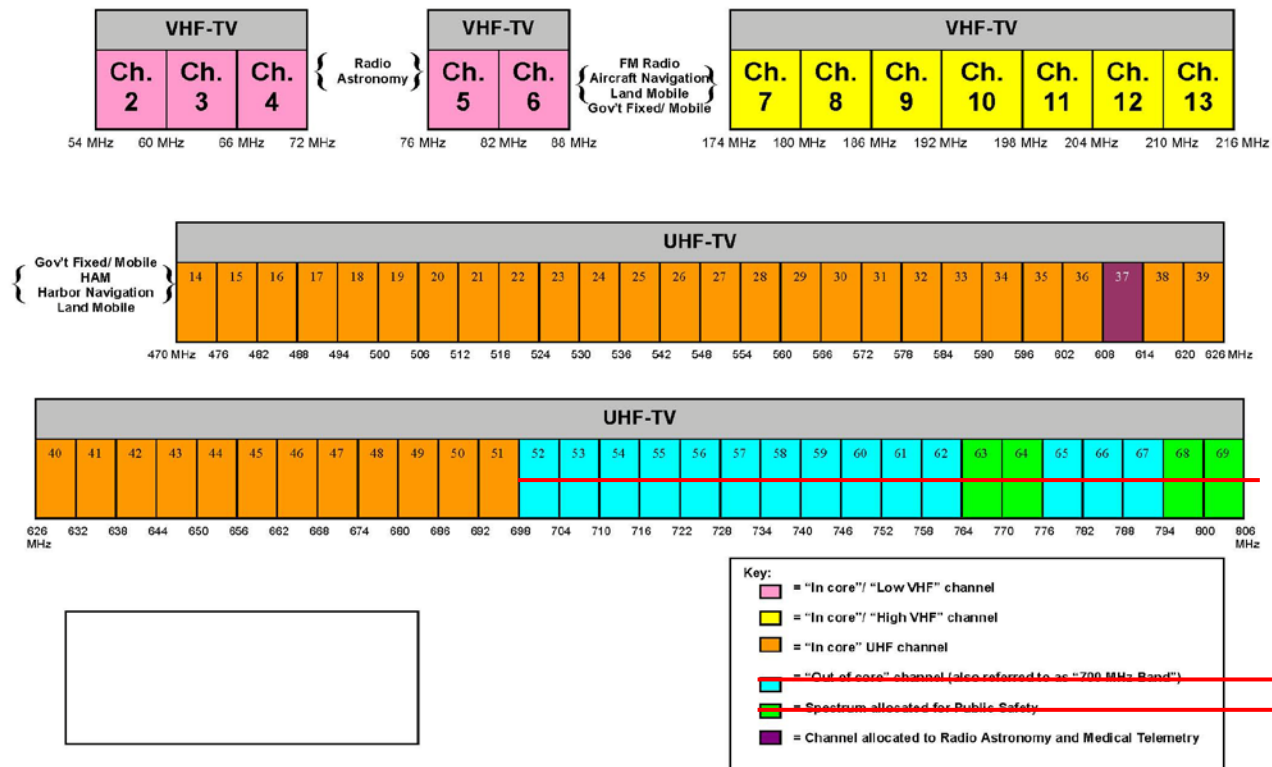
Repurposed in DTV transition

Each of ≈2,500 TV licenses includes

- ☐ Channel, location, and power restrictions
- ☐ Protection from interference in current service area
  - ☐ From same channel or adjacent-channel stations
- ☐ "Must-carry" rights on cable and satellite TV
- ☐ Statute lets FCC retune non-participating station *within home bands* (compensating retuning costs)
  - ☐ Mandates "all reasonable efforts" to preserve interference-free population coverage
- ☐ Stations can bid
  - ☐ to go off-air
 - ☐ to move to a lower band (preserving must-carry rights)

Descending Clock Auctions

- **Definition**: A *descending clock auction* is a dynamic mechanism in which bidder-specific prices for different options are initialized at reserves and descend over time, and each bidder holds an option. In every round, the auction:
  - Selects a bidder who can feasibly "quit" – assigned to home band
  - Decrements the bidder's price for its current option (and perhaps others)
  - Gives the bidder the opportunity to switch options or quit
- When no more bidders can feasibly quit, auction ends, accepting all still-active bids at their final prices
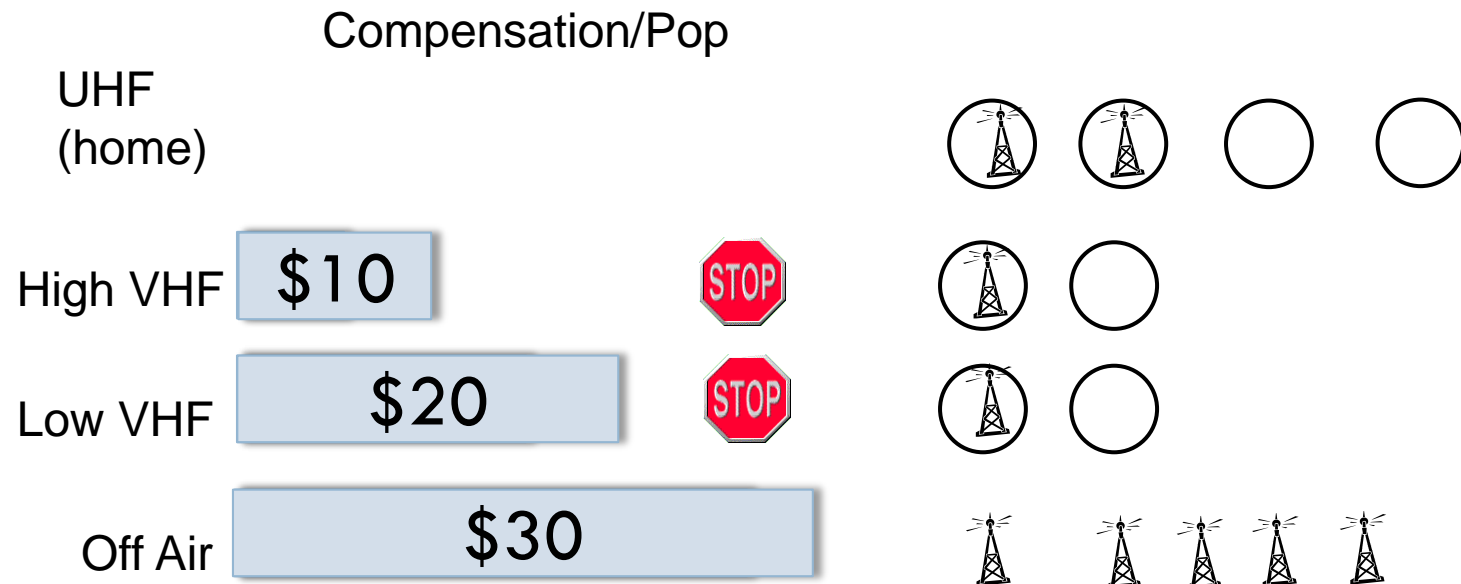
Example: Ladder Auction

Compensation/Pop

UHF
(home)

High VHF $10 STOP ?

Low VHF $20

?

Off Air $30
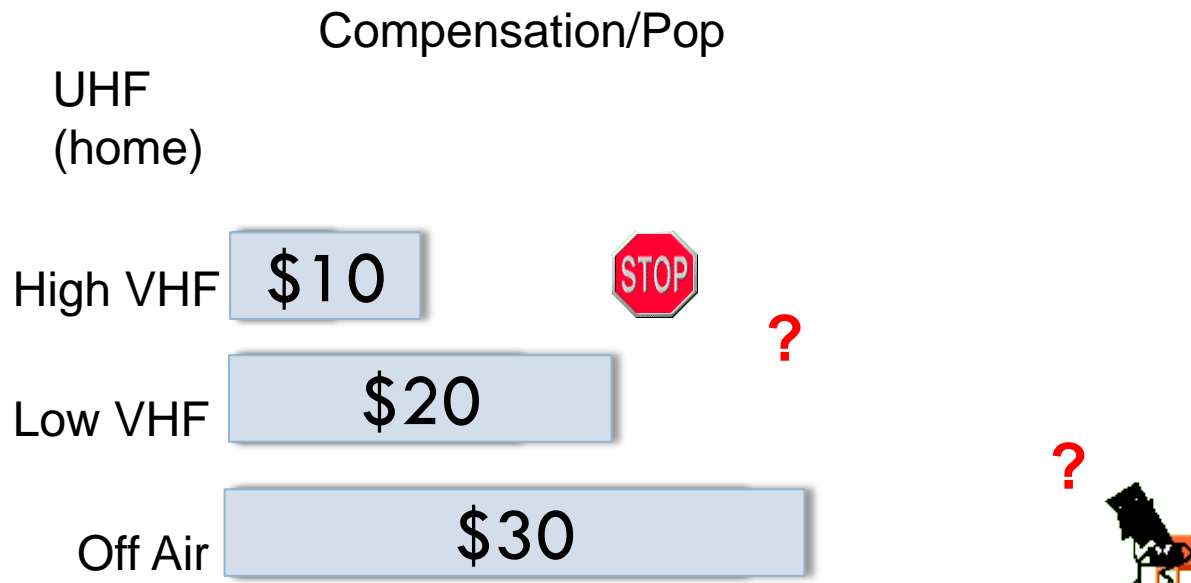
- Bidders can only move up

- A band is infeasible for bidder ⟹

his price for it is reduced by the same amount as his current band

Ladder Auction with Homogeneous UHF stations

Compensation/Pop

UHF (home)

High VHF $10 STOP

Low VHF $20 STOP

Off Air $30

☐ Generally: Stations with different coverage areas and/or different home bands will have different feasible moves and so will face different price paths

Equivalent Sealed-Bid Auction

- "Greedy" heuristic algorithm iteratively rejects the highest-scoring bid that is feasible to reject
  - *Score* is an increasing function of bid (e.g. = bid/"volume")
  - *Feasibility* checked with possible repacking of other stations

Active Bids

- Each winning bid is paid its "threshold price" - maximal bid amount that would have won

- Equivalence: Scoring in Heuristic Sealed-Bid Auction ⟺ Price Reduction Rules in Clock Auction
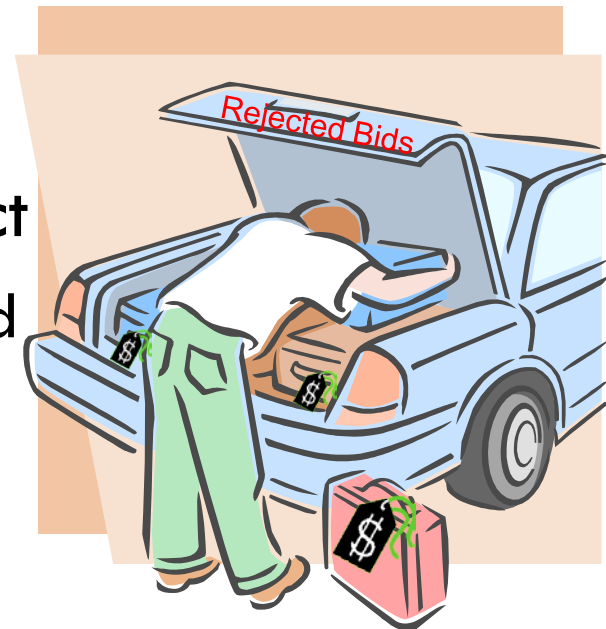
Strategy-Proofness

- A *single-minded bidder* is a single-station owner who bids on just one option and knows its "private" value

- Both Clock Auction and Sealed-Bid Heuristic Auction with threshold prices are *strategy-proof* for single-minded bidders: such a bidder finds it optimal to bid his true value, regardless of others' bids.

  - This holds for *any* scoring and *any* feasibility checking that does not condition on active bids

  - Can condition on current clock prices (=sealed-bid "threshold prices"): E.g. total cost too high relative to forward auction revenue $\Rightarrow$ reduce clearing target

Clock Auction: Simpler for Bidders

- Optimality of truthful bidding for single-minded bidders is obvious, does not require understanding/trusting auction algorithm
  - Cf. Sealed-Bid Heuristic Auction with threshold pricing: a bidder may suspect that his bid affects feasibility checking
- Simpler bidding for bidders who don't know values in advance or are "multi-minded"
  - Winners need not reveal – or even know – exact values
  - Information feedback can reveal spectrum resale value
  - Multi-station owners may be allowed to switch among substitutable stations

Proxy Bidding: Clock/Sealed Hybrids

- "Proxy bidding" option may appeal to some bidders
  - Proxy bids may be modified at any time in any way that wouldn't have affected the auction's preceding rounds
- "Mandatory" proxy bidding to speed up auction:
  - Intra-round bidding: permits larger price decrements without impacting efficiency/cost
  - Sealed VHF bids from UHF stations already placed on air?
  - Sealed bids following clearing target reduction?
- These approaches would help reduce bidder participation time in the clock auction, while preserving most of its advantages

Clock Auction: Computations

- Clock auction requires the same feasibility checks as Sealed-Bid Heuristic Auction

- Feasibility checking is an NP-hard problem
  - ≈130,000 pairwise constraints ("graph coloring")
  - even harder with an aggregate interference cap
  - fail to find a feasible packing when it exists $\Longrightarrow$ raise the cost

- Feasibility checking for adding different stations and in different bands can be parallelized

- "Bottleneck" = runtime of a single feasibility check (e.g. 30-min cap?)

- Pre-computations – when participants are known, and on nights/weekends during auction – may speed it up

Alternative: *Optimization-Based Sealed-Bid Auction*

- Maximize total broadcast value according to bids s.t. interference constraints and a given clearing goal.
  - May incorporate revenue goal by optimizing total "virtual value" (Myerson) based on stations' characteristics
- Optimization is NP-hard (harder than feasibility checking) – only approximate optimum can be found
- Payments to winners:
  - Vickrey prices to induce truthful bidding?
  - Paid as bid?

Paid-as-bid?

- Broadcaster's optimal bid depends on its estimates of
  - bids of neighboring stations
  - algorithm used for computing the assignment
  - interference constraints used in the algorithm
  - bids in the forward auction, which help determine how much spectrum is repurposed
  - post-auction value of licenses (common-value element)
- $\Longrightarrow$ Difficult, expensive for broadcasters to bid well!
  - ***Reduces participation in the auction.***

Vickrey: Computational Problems

- Bidder's Vickrey Premium = Total Value – Total Value if he didn't bid

- Both amounts much larger than the price itself $\implies$ small % errors in optimization can lead to large % errors in prices

- Example (hypothetical):
  - True Vickrey Premium $\qquad\qquad = 100 - 99 = 1$
  - Approximate Vickrey Premium $\qquad = 100 - 96 = 4$
  - 3% error in "second optimization" $\implies$ 300% overpayment
  - *Underpayment* may also happen when "second optimization" is *more* precise than overall optimization

- ***Likelihood of pricing errors destroys incentives for truthful bidding $\implies$ ruins the auction's supposed efficiency***

Vickrey vs. Heuristic: Homogenous-DMA Case

☐ All stations within DMA are identical and no cross-DMA interference $\Longrightarrow$ both approaches yield efficient clearing at (highest) post-auction resale equilibrium prices
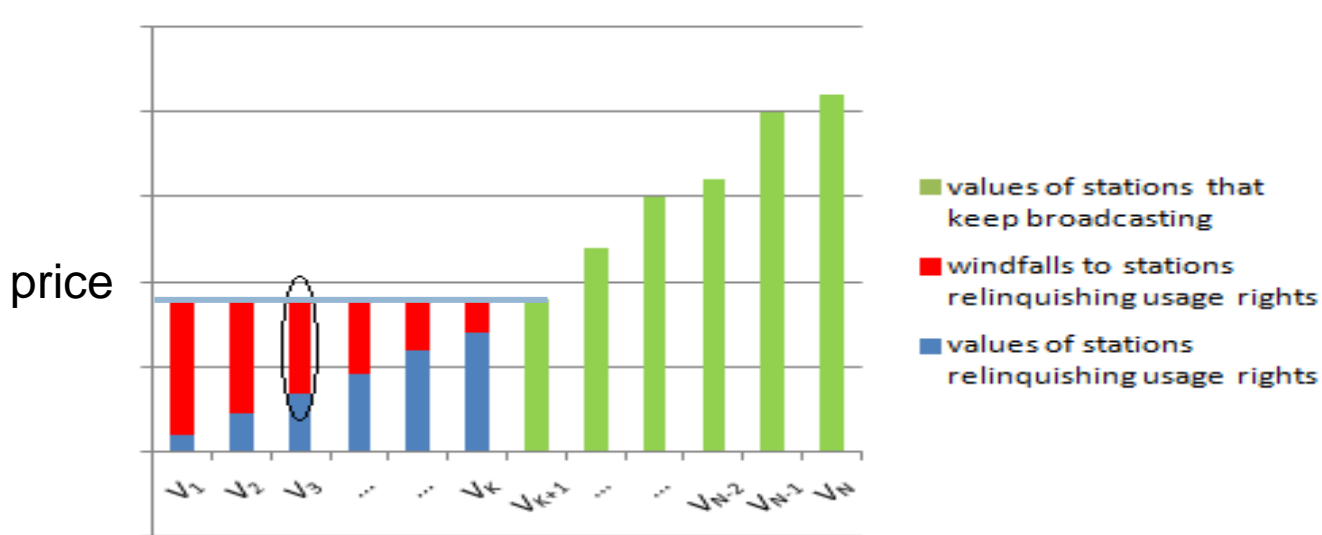
☐ *Multi-band* (ladder) auction also yields Vickrey outcome, even for bidders choosing between off-air and VHF options

   ☐ Jumps over bands can be avoided

Generally: under Substitutes

□ An assignment rule for single-minded bidders

  ◻ is *monotonic* if raising a bid cannot cause it to win

  ◻ has the *substitute property* if raising a bid cannot cause another bid to lose

□ Any monotonic assignment rule with the substitute property can be implemented with a clock auction

  ◻ *Proof:* can safely decrement price to any bidder who wouldn't win given current prices

□ However: deciding which price(s) to decrement next for optimizing is computationally hard

Vickrey with Complementarity
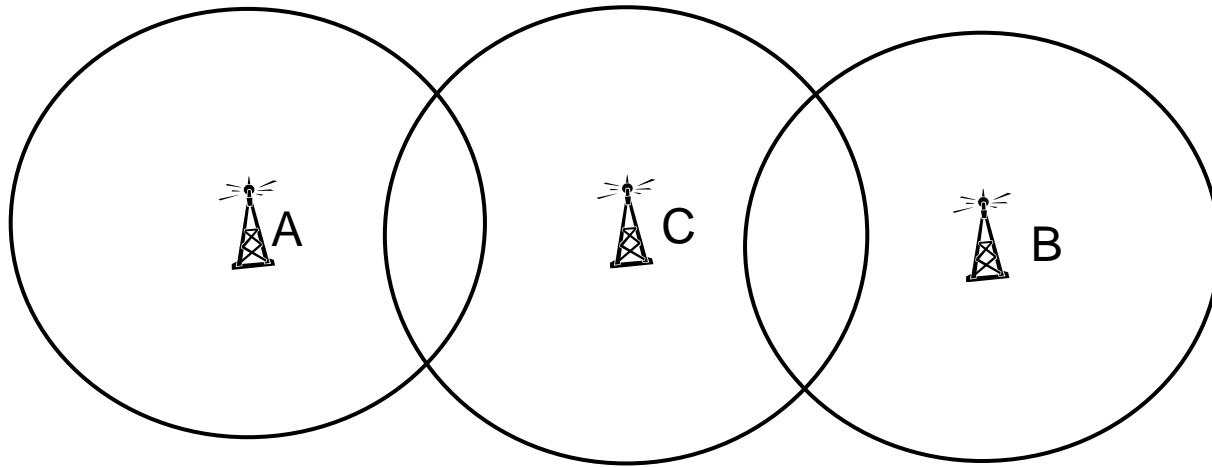
- One channel available $\implies$ can assign either A+B or C

- $A+B < C \implies$ assign C, Vickrey prices $p_A = C - B$, $p_B = C - A$

- Not *group* strategy-proof: A,B maximize p_A, p_B by bidding 0

- Pays "too much": $p_A + p_B = 2C-A-B > C$.

  - Cf. *paid-as-bid* optimizing auction: full-info Nash equilibrium cannot cost more than C (otherwise C would underbid)

  - Cf. heuristic with Volume(C) = 2: costs C when $A,B < C/2$

Advantages of Clock/Heuristic Auction (for single-minded bidders)

- *Group Strategy-Proof:* No group of bidders can benefit all of its members by bidding non-truthfully, no matter what other bidders do

- Need not cost more than *paid-as-bid* auction with the same assignment rule: under full info,

  - The paid-as-bid auction has a Nash equilibrium that is equivalent to the clock auction outcome

  - This is a unique outcome surviving iterated deletion of weakly dominated strategies (under non-bossiness)

- Milgrom-Segal (2012)

Cost of Heuristic/Clock vs. Vickrey

- *Simulations* by DAC: Single-minded UHF bidders with realistic interference constraints and bid values
  - Nationwide scenario: approximate Vickrey
  - Regional scenarios: exact Vickrey
- Heuristic – even with imprecise feasibility checking - yields comparable or lower cost than Vickrey
  - despite somewhat lower efficiency

Effect of Station Scoring on Cost

1. Increases efficiency by favoring to accept stations that would create more interference

2. Reduces windfalls by bringing prices closer to stations' resale values (e.g. per pop)

   ❑ E.g. give lower "volumes" to Class-A stations (which tend to have lower values/pop)

Reference Pricing

- High reserve prices encourage participation, facilitate uniform clearing

- But in some areas with limited competition, some stations may need to be acquired at reserve price

- Solution: combine high opening prices with "dynamic reference prices" – refuse to pay "too much more" (per volume) than prices already accepted by other stations

  - Other stations create "yardstick competition" – reveal information about TV spectrum value